On the Nature of the Hydrogen Flocculi and their Structure at Different Levels in the Solar Atmosphere.

By George E. Hale, For. Mem. R.S., and Ferdinand Ellerman.

(Received November 2,—Read November 25, 1909.)

[Plate 1.]

If we compare two monochromatic photographs of the sun, taken respectively with the H_2 line of calcium and the $H\alpha$ line of hydrogen, we find that dark areas on the hydrogen plate correspond roughly in form with bright areas on the calcium plate. The exquisite details of structure, which on sharply defined $H\alpha$ negatives appear like the delicate tracery of hoar-frost, have no counterpart on H_2 negatives, where the bright clouds of calcium vapour, or *flocculi,* more nearly resemble cumulus clouds in the earth's atmosphere. Thus there is no precise agreement in form, though the larger regions occupied by dark hydrogen and bright calcium flocculi usually do not differ greatly in area or general outline. In certain places dark hydrogen seems to be replaced by bright hydrogen, which frequently assumes the form of a narrow ring partially or completely encircling a sun-spot.* Brilliantly luminous areas, rapidly changing in form, are often photographed with $H\alpha$, usually in the neighbourhood of active spots (see Plate 1, fig. 1).

The bright hydrogen flocculi of the quiescent or slowly changing type, and the very bright hydrogen flocculi of the rapidly changing or eruptive type, are commonly found in regions where H_2 or K_2 photographs also show bright calcium flocculi. Moreover, dark calcium flocculi, usually long and slender in form, are often shown by H_2 or K_2 plates to correspond in position with exceptionally dark hydrogen flocculi.† These dark calcium flocculi have recently been photographed by Deslandres with dispersion sufficiently high to isolate the K_3 line. In this way they are found to be much more numerous and extensive than when photographed with lower dispersion.

Observations of the spectra of these regions, made on Mount Wilson several years ago, showed the H_3 and K_3 lines, as well as the hydrogen lines, to be greatly strengthened and also widened.‡ The increase of absorption is so

* Hale and Ellerman, "The Rumford Spectroheliograph of the Yerkes Observatory," 'Publications of the Yerkes Observatory,' vol. 3, part 1; 'Contributions from the Mount Wilson Solar Observatory,' No. 7, p. 9; 'Astrophysical Journal,' vol. 23, p. 62, 1906.

† Hale and Ellerman, 'The Rumford Spectroheliograph,' p. 19.

‡ Hale, 'Report of the Director of the Mount Wilson Solar Observatory for the Year ending September 30, 1906,' p. 69; "Preliminary Note on the Rotation of the Sun as determined from the Motions of the Hydrogen Flocculi," 'Contributions from the Mount Wilson Solar Observatory,' No. 25, 'Astrophysical Journal,' vol. 27, April, 1908.

marked that $H\epsilon$, which is usually extremely faint in the solar spectrum, appears as a strong dark line in the photographs. We accordingly concluded that the very dark hydrogen flocculi are due to increased absorption, probably resulting from the great depth and decreased temperature of the hydrogen gas in these regions of the solar atmosphere. The strengthening of the high-level H_3 and K_3 lines, and the fact that photographs of such objects at the sun's limb show them to be prominences,* seemed to leave little room for doubt as to the correctness of this view. Similar reasoning led us to the opinion that the less dark hydrogen flocculi are also due to increased absorption, while the bright flocculi represent regions of increased radiation.

In the present paper we wish to discuss briefly the following hypotheses, which have been advanced to account for the fact that the greater part of the hydrogen flocculi appear dark on spectroheliograph plates.

Explanations of the Hydrogen Flocculi.

(1) "The regions where calcium exists correspond to those where hydrogen is absent" (W. J. S. Lockyer).†

(2) "L'apparition des plages faculaires noires, annoncée depuis 1903, est due, au moins pour une large part, non à des particularités dans le pouvoir émissif ou absorbant de l'hydrogène, mais à une simple cause instrumentale, à un défaut primordial du spectrohéliographe qui, ayant une fente de largeur constante, ne peut isoler complètement une raie de largeur variable" (Deslandres).‡

(3) The hydrogen lines are strengthened (and consequently widened) in the hydrogen flocculi, which therefore represent regions of increased absorption (Hale).

(4) The dark and bright areas on spectroheliograph plates are caused by anomalous refraction in the solar atmosphere (Julius).

Lockyer's view that the dark objects on the photographs indicate a deficiency of hydrogen in these regions of the solar atmosphere appears to us untenable. Observations at the sun's limb invariably show that hydrogen and calcium do not avoid one another, but occupy the same general regions of the chromosphere and prominences, though the forms of the prominences, when photographed with the hydrogen and calcium lines, are not precisely alike. As already remarked, the high-level dark calcium flocculi are

* Michie Smith, "Report of the Meeting of the Royal Astronomical Society," 'Observatory,' June, 1907. Fox, 'Astrophysical Journal,' vol. 28, p. 117, 1908.

† Lockyer, 'Nature,' April 28, 1904.

‡ Deslandres et d'Azambuja, "Examen critique des Images Monochromatiques du Soleil avec les Raies de l'Hydrogène," 'Comptes Rendus,' vol. 148, p. 1239, 1909.

represented on hydrogen photographs by dark objects of similar form, which appear as prominences when seen at the sun's limb. In these flocculi the hydrogen lines are both strengthened and widened, this effect being very conspicuously shown by $H\epsilon$. In the ordinary dark hydrogen flocculi the hydrogen lines are also strengthened and widened (see fig. 2). If these lines are due to hydrogen in the solar atmosphere, an increase of intensity cannot be supposed to result from a deficiency of this gas. We therefore think we are justified in rejecting Lockyer's hypothesis.

In the paper quoted above, Deslandres and d'Azambuja deny that the dark hydrogen flocculi are mainly due to variations in the emissive or absorbing power of hydrogen, and attribute their presence to an instrumental cause. Using a very narrow slit, they find that these dark flocculi are not shown on the photographs when the slit is set exactly at the centre of the line, but appear only when it receives light from the edge of $H\alpha$. In a comparative study of the $H\alpha$ line of hydrogen and the K line of calcium, they observe: "Que les élargissements de $H\alpha$, dans la grande majorité des cas, correspondent à des flocculi brillants de K_2; cela est vrai surtout pour les flocculi d'éclat moyen et de largeur moyenne. L'élargissement et l'éclat de la raie rouge paraissent aussi liés à la largeur et à l'éclat de la raie K_3. Enfin, les deux raies offrent les mêmes variations de vitesses radiales, et même, au moins sur ces premières épreuves, les variations ont paru plus fortes avec l'hydrogène. En résumé, si on laisse de côté ces points de détails, la relation générale signalée plus haut est vérifiée nettement dans son ensemble; or elle explique simplement les plages faculaires noires signalées souvent dans les images précédentes de l'hydrogène."*

The dark hydrogen flocculi are thus attributed to the widening of the $H\alpha$ line in certain regions of the sun, which are photographically recorded because of a "fundamental defect" of the spectroheliograph. Let us see whether this conclusion is in reality opposed to the hypothesis that the dark hydrogen flocculi are absorption phenomena.

It is generally held, in accordance with Kirchhoff's views, that the dark hydrogen lines of the solar spectrum are produced by the absorption of hydrogen gas in the sun's atmosphere. Their intensity is determined by the degree of this absorption. An increase in the intensity of a spectral line is ordinarily accompanied by an increase in its width. Thus the increased width of $H\alpha$ in the regions occupied by the dark hydrogen flocculi is precisely what would be anticipated on the absorption hypothesis.

Photographs of the $H\alpha$ line, made in the second and third spectra of a Rowland grating having 14,438 lines to the inch, used in the 30-foot spectro-

* *Ibid.*, p. 1238.

graph of the tower telescope on Mount Wilson, show that its intensity and width differ greatly in different regions of the sun. The brightest parts of the line correspond to bright hydrogen flocculi, while the darkest parts represent dark flocculi. In general, the widest parts of the line correspond with its darkest parts. Within the boundaries of the dark line a single or multiple bright line is often photographed. Sometimes its appearance resembles that of the calcium lines H_2 and H_3, *i.e.* the bright line lying on its dark background is split into two components by a central dark line. In other regions the bright line is divided into a larger number of components varying in width and separation.

All of these phenomena are most marked in active regions of the sun. But in regions of the solar surface far removed from spots and eruptions, the $H\alpha$ line also shows distinct differences in intensity and width. At the centre of the line the differences of intensity are small, but near the edges they are sufficient to produce decided differences in width. It would be impossible, without great dispersion, to study the change of intensity from centre to edge advantageously in photographs of the $H\alpha$ line. We therefore have recourse to the spectroheliograph, which affords a most delicate method of recording any differences in the appearance of the flocculi which depend upon the position of the camera slit with respect to the centre of the line.

In our investigations of the hydrogen flocculi with the Rumford spectroheliograph, photographs made with the camera slit set on different parts of the $H\beta$ line showed differences in structure, which were ascribed to differences in the level of the absorbing gas in the solar atmosphere.* It was subsequently found on Mount Wilson that the central part of $H\alpha$ gives the bright flocculi, which are not recorded when the camera slit is set on the wings,† and that dark flocculi, showing vortex structure, can also be photographed when no light from the wings enters the camera slit. Deslandres and d'Azambuja were the first to point out, however, that the dark flocculi photographed with a very narrow slit set at the centre of $H\alpha$ differ decidedly in form and appearance from those obtained with the light of the wings.‡ We have recently repeated this work with $H\alpha$, and extended it to $H\beta$ and $H\gamma$, using a Michelson grating having 500 lines to the millimetre, mounted in a spectroheliograph of 30 feet (9·1 m.) focal length.

* Hale and Ellerman, "The Rumford Spectroheliograph," p. 21.

† Hale, 'Comptes Rendus,' vol. 148, p. 1025, 1909.

‡ Deslandres et d'Azambuja, 'Comptes Rendus,' vol. 148, p. 1014, 1909.

The 30-foot Spectroheliograph.

The 30-foot spectroheliograph is mounted in a well excavated in the earth beneath the 60-foot tower telescope, side by side with the 30-foot spectrograph described in a previous paper.* It is of the Littrow form, with fixed camera slit $3\frac{1}{2}$ inches (8·9 cm.) long, thus permitting only a part of the solar images (6·7 inches = 17 cm. in diameter) to be photographed on a single plate. The objective which serves for both collimator and camera is of 8 inches (20 cm.) aperture and 30 feet (9·1 m.) focal length. It is mounted near the bottom of the well, where the temperature range is very small. The dispersing member of the instrument is either (1) a large liquid prism of 60° angle; (2) a plane grating having 500 lines per millimetre; or (3) a glass prism of 64° angle belonging to the 5-foot spectroheliograph.† Only about half of the light is utilised when the glass prism is employed, on account of the small size of the prism faces (at present a larger glass prism is not available). The liquid prism, which has glass faces 12 inches (30 cm.) in diameter, gave very fine definition, but was so sensitive to temperature change that apparatus for obviating this difficulty has been designed and will soon be constructed.

It is sometimes desirable to take simultaneous photographs of the same region of the sun with two or three lines in different parts of the spectrum. For this purpose three camera slits are provided for use, singly or together. Ordinarily a single mirror is used to return the light through the prism. But in case simultaneous photographs are to be taken with different parts of the same line ($H\alpha$, for example), two mirrors are used, so adjusted as to separate in the focal plane of the camera the spectra produced by light coming through the opposite halves (ends) of the prism, or two gratings can be used without the mirrors.

The motion of the solar image across the collimator slit is produced by a system of three mirrors supported on a carriage mounted on steel balls.‡ A screw, driven by an electric motor, moves the mirror system at a uniform rate over the slit. As the solar image travels at twice this rate, the carriage which bears the photographic plate (above the fixed camera slits) is connected so as to move at twice the speed of the mirror carriage. The speed of the

* Hale, "The Tower Telescope of the Mount Wilson Solar Observatory," 'Contributions from the Mount Wilson Solar Observatory,' No. 23; 'Astrophysical Journal,' vol. 27, p. 204, 1908.

† Hale and Ellerman, "The Five-foot Spectroheliograph of the Solar Observatory," 'Contributions from the Solar Observatory,' No. 7; 'Astrophysical Journal,' vol. 23, p. 54, 1906.

‡ This device is described in a note by Hale, 'Astrophysical Journal,' vol. 10, p. 288, 1899.

motor can be varied through a wide range by changing the position of the armature with respect to the field coils.

This form of spectroheliograph has proved so satisfactory that a similar system of moving mirrors will be employed on the combined spectrograph and spectroheliograph of 75 feet (22·9 m.) focal length now being designed for the 150-foot (45·7 m.) tower telescope. It had been feared that difficulties might be encountered because of scattered light from the three mirror surfaces and scattered and reflected light from the collimator objective. The excellent contrast of the photographs, however, even when very long exposures are given with the camera slit set at the centre of a dark line, indicates that these difficulties are of no practical importance. The "ghosts" from the collimator objective are cut off by a bar supported on its cell, and the scattered light is too feeble to be harmful.

Photographs of the Flocculi with different Parts of Hα.

Most of our high dispersion Hα photographs have been made with the 60° fluid prism, or in the first order of the grating. In the case of this prism, the linear dispersion at Hα is 1 Ångström = 0·28 mm. For the grating, 1 Ångström = 0·55 mm. in the same region of the first spectrum. On account of its higher dispersion in the red, and also because of the sensitiveness of the prism to temperature change, the grating was used for the majority of the experiments.

In the 5-foot spectroheliograph of the Snow telescope, the linear dispersion of Hα, given by two prisms, is 1 Ångström = 0·04 mm. The width of the camera slit used for Hα is from 0·06 to 0·075 mm. Thus, since the width of Hα, to the extreme limit of the wings, is about 1·7 Ångströms,* the entire line passes through the camera slit to the photographic plate. We have recognised from the outset that the effect of the comparatively low dispersion of the 5-foot spectroheliograph must be to record in a single image the flocculi belonging to different levels. Thus the long dark filaments, which are characteristic high level phenomena, have been photographed with this dispersion (or with that of the Rumford spectroheliograph) since 1903, together with the flocculi of lower levels. The high dispersion of the 30-foot spectroheliograph permits the flocculi of different levels to be separated from one another, by setting the camera slit at different distances from the centre of the Hα line. The width of the main body of the Hα line, within the wings, is about 1·1 Ångströms. The width of the camera slit ranges from 0·2 to 0·4 Ångström. If we make the slit 0·3 Ångström wide, and set it

* Jewell, 'Astrophysical Journal,' vol. 9, p. 212, 1809.

0·3 Ångström from the centre of the line, we obtain a solar image in which the hydrogen flocculi closely resemble those shown on a photograph taken simultaneously with the 5-foot spectroheliograph. A good illustration is afforded by photographs made with the two instruments on August 27, 1909, which we have compared in a Zeiss stereocomparator, using the monocular attachment.

When the camera slit is set nearer the edge of Hα, similar images of the flocculi are obtained. At the extreme edge of the line, the dark flocculi photographed are finer and sharper than in the previous case, and are shown with less contrast. The differences in structure are similar to those observed when comparing H_1 with H_2 calcium flocculi.

At the centre of Hα, as Deslandres has remarked, the flocculi differ decidedly in appearance. The background is much darker, and most of the dark flocculi are shown with less contrast than when the camera slit is set 0·3 Ångström from the centre of the line. The "filaments," however, which represent the highest level, appear with increased contrast, and hence are very conspicuous on the photographs. The bright flocculi, as we have already mentioned, are also shown with increased contrast, and cover extensive areas.

In the paper on "Solar Vortices,"* it was shown that the high-level dark flocculi, or filaments, frequently share with the dark flocculi of lower levels the characteristic curved structure, which gives them the appearance of vortices or lines of force in a magnetic field. This structure is also shown by the smaller flocculi, less dark than the filaments, which are recorded when a narrow camera slit is used at the centre of Hα. Nevertheless, the vortices are better shown when the slit is nearer the edge of the line.

The results obtained in the high dispersion work with Hα thus show that there is a progressive change in the structure of the flocculi as the camera slit is moved from the centre to the edge of the line. When the slit is set at a point between the centre and the edge, the structure closely resembles that obtained with the lower dispersion of the 5-foot spectroheliograph, with a camera slit wide enough to transmit the entire line, including the wings.

The Flocculi as photographed with Hβ, Hγ, *and* Hδ.

In our work with the Rumford spectroheliograph, the hydrogen lines Hβ, Hγ, and Hδ were employed. Some of the photographs obtained with this instrument are produced in the paper to which we have already referred.†

* Hale, 'Contributions from the Mount Wilson Solar Observatory,' No. 26; 'Astrophysical Journal,' vol. 28, September, 1908.

† Hale and Ellerman, "The Rumford Spectroheliograph," Plates 9 and 11.

These show a remarkable structure, to which attention was called at the time.* Many of the photographs taken with Hβ (see, for example, "The Rumford Spectroheliograph," fig. 2, Plate 11) forcibly recall the appearance of the lines of force in a magnetic field. A preliminary comparative study of the flocculi, as photographed with different hydrogen lines, indicated a progressive change in structure in passing from Hδ to Hβ.

Prior to March, 1908, the Hδ line was used for the daily series of solar photographs made on Mount Wilson with the 5-foot spectroheliograph and the Snow telescope. At that time (as explained elsewhere†) the first experiments were made with Hα. The vortices associated with sun-spots, which are sometimes of simple pattern‡ and sometimes extremely complex in appearance, were easily photographed with Hα, while only traces of them were shown with Hδ. For reasons set forth in the paper mentioned, it was concluded that the vortex structure, which is rarely or never shown by the H_1 or H_2 calcium flocculi, is a phenomenon characteristic of comparatively high levels in the solar atmosphere.

We have just seen, however, that this structure is best photographed when the camera slit is near the edge of Hα, while curved stream-lines also appear in the very high level flocculi obtained with the slit at the centre of this line. It thus becomes necessary to determine more precisely the relative levels represented by the various hydrogen lines.

Photographs of the Hβ flocculi have recently been obtained with the 5-foot spectroheliograph, which are of much better quality than our earlier ones. These show the vortices very plainly, though not quite so well as the Hα plates. The best Hγ photographs also show the vortex structure, but still less clearly than those made with Hβ. Finally, the Hδ images, even when taken under the best conditions, give comparatively little evidence of the existence of vortices.

In the work with Hβ, Hγ, and Hδ the width of the camera slit of the 5-foot spectroheliograph was such as to transmit the main body of the lines, without the wings. It next became important to determine, with higher dispersion, the exact nature of the image given by each narrow section of these lines. Accordingly, several series of photographs were taken with the 30-foot spectroheliograph, using a narrow camera slit set on various parts of Hβ and Hγ. The 64° glass prism was employed, the dispersion for Hβ being 1 Ångström = 0·67 mm., and for Hγ 1 Ångström = 0·98 mm. The width of

* *Ibid.*, p. 20.

† Hale, "Solar Vortices," p. 2.

‡ See 'Report of the Director of the Mount Wilson Solar Observatory for the Year ending September 30, 1908,' Plate 6.

Hγ, including the wings, is about 0·75 Ångström. The width of the camera slit ranged from 0·15 Ångström to 0·20 Ångström. In such photographs the curved vortex structure is shown only when the slit was at or near the centre of the line. Toward the edges of the line the flocculi become finer and sharper, the contrast decreases, the dark umbræ of the spot grow larger, and the penumbræ, completely hidden at the higher levels represented by the centre of the line, become visible, surrounded by the bright regions of the faculæ.

As the characteristic structure of the vortices is shown by the central part of Hγ, and as similar images are obtained when the camera slit is set near the edge of Hα, we may conclude that approximately the same level in the solar atmosphere is represented in both cases. Below this level, two (perhaps three) distinct levels can easily be distinguished with Hγ, and probably equally well with Hα, when sufficient dispersion is employed.

Absorption in the Flocculi.

These results confirm the hypothesis that the dark hydrogen flocculi are regions of increased absorption. When the slit is at the centre of Hγ it is far removed from the edges of the line, and variations in its width, supposed by M. Deslandres to account for the dark Hα flocculi, can have no effect. As already remarked, the results obtained with Hα alone are sufficient to demonstrate this, as the dark flocculi of the vortices can be photographed when no light from the edges of the line falls on the slit. The marked variations of intensity, which might be expected to extend across the central part of Hα, are probably masked by the absorption at higher levels. In the case of Hγ such absorption is not sufficient to produce a masking effect, as this line is relatively weak in the upper chromosphere and prominences.* Our spectrum photographs show Hγ to be more strengthened than Hα over the dark hydrogen flocculi.

Level of the Vortex Structure.

We may now consider the bearing of these results on the nature of the vortex structure shown on Hα and Hβ photographs.† In the paper on "Solar Vortices" it was argued that, since the vortex structure was clearly shown by Hα, less distinctly by the more refrangible lines, and still less so by the calcium line H_2, the simplest way to account for the differences in

* "Solar Vortices," p. 3.

† We use the term "vortex" as a convenient designation of the vortex-like structure of the hydrogen flocculi commonly photographed near sun-spots and at other points on the sun. The question whether these phenomena are actual vortices will be discussed later.

form is to ascribe them to differences in the mean level represented by these lines. The results obtained with high dispersion appear to confirm this view. If the same level is represented by the centre of $H\gamma$ and a point between the centre and edge of $H\alpha$, and if the centre of $H\alpha$ represents a still higher level, the average level given by the entire $H\alpha$ line is higher than that given by the entire $H\gamma$ line. But have we any warrant for the view that the dark flocculi photographed at the centre of $H\gamma$ represent a higher average level than that of the bright H_2 flocculi of calcium?

The change in character of the hydrogen lines is progressive, indicating increasing average levels of absorption as we advance from $H\delta$ to $H\alpha$. Some of our reasons for the belief that the dark $H\delta$ flocculi are higher, on the average, than the corresponding bright H_2 calcium flocculi have already been given,* but they may be repeated here. As compared with the bright H_2 flocculi, the dark $H\delta$ flocculi show:—

1. More rapid changes in position and form.
2. A slight displacement away from the centre of the sun, when corresponding H_2 and $H\delta$ flocculi near the limb are compared in the stereo-comparator, using the monocular attachment.†
3. A different law of rotation.

The law of the solar rotation, as determined from the motions of the bright H_2 calcium flocculi,‡ shows a well-defined equatorial acceleration, somewhat smaller than that found by Spoerer for the spots. The dark $H\delta$ flocculi, however, give no evidence of equatorial acceleration.§ On account of their greater proper motions and more rapid changes in form, the hydrogen flocculi are ill-suited for an investigation of this kind, and the above conclusion is entitled to but little weight.|| Nevertheless, the spectrographic investigations of Adams, which give an accurate determination of the rotation law at different levels in the solar atmosphere, also show a very small equatorial acceleration for $H\alpha$, and indicates that this line represents

* Hale, "Solar Vortices"; "Preliminary Note on the Rotation of the Sun as determined from the Motions of the Hydrogen Flocculi," 'Contributions from the Mount Wilson Solar Observatory,' No. 25; 'Astrophysical Journal,' vol. 27, April, 1908.

† This effect is doubtful, because irregular refraction in the earth's atmosphere frequently produces distortion of the photographs. It will be tested as soon as simultaneous photographs can be taken with the two lines.

‡ Hale and Fox, 'Publications of the Carnegie Institution,' No. 93; Fox, 'Science,' April 19, 1907; Hale, 'Preliminary Note on the Rotation of the Sun as determined from the Motions of the Hydrogen Flocculi,' p. 4.

§ Hale, *ibid.*, p. 4.

|| An improved method of measuring the daily motion of the hydrogen flocculi has been devised, and will be tried as soon as other work permits.

a higher level than Hγ and Hδ.* The explanation of this, as Adams points out, is suggested by the strengthening of Hα and Hβ in the spectrum of the sun's disc near the limb, where Hγ and Hδ are slightly weakened. This change of relative intensities, and a similar change observed in the upper part of the prominences,† is probably due to the reduction of temperature at increasing distances from the photosphere.‡

Anomalous Refraction.

While the results obtained in the high dispersion work with the hydrogen lines seem to confirm the absorption hypothesis, it must not be forgotten that they are also in accord with a prediction of Julius, who ascribes the flocculi to anomalous refraction in the solar atmosphere. During his visit to Mount Wilson in 1907, Prof. Julius passed a beam of sunlight through an electric furnace containing sodium vapour, and photographed the anomalous refraction phenomena with the 5-foot spectroheliograph. A very slight density gradient was sufficient to deviate the sunlight from its straight path, and in this way appearances analogous to those of the flocculi were produced. In these experiments the source of light was a narrow slit, but Julius gives reasons for his belief that even with an extended source like the sun, small density gradients may give rise to similar phenomena. He also points out that light from the central part of Hδ may give images of the flocculi similar to those obtained when the camera slit is set near the edge of Hα.§

A general discussion of the effects of anomalous refraction in the solar atmosphere cannot be undertaken to advantage until many more observations have been made. It may be of interest, however, to consider the probable bearing on this subject of the results already obtained.

In the electric furnace experiments, the reduction of intensity of the sunlight, with a given density gradient, increased as the camera slit was moved toward the centre of the sodium line, and was of equal magnitude at equal distances from the centre on the red and violet sides. In the sun, however, it can hardly be supposed that similar effects would be observed if on opposite sides of a line anomalous refraction were the sole cause of the flocculi. Light would be brought to the collimator slit along very different

* Adams, "Spectroscopic Investigations of the Rotation of the Sun during the Year 1908," 'Contributions from the Mount Wilson Solar Observatory,' No. 33 ; 'Astrophysica Journal,' vol. 29, March, 1909.

† "Solar Vortices," p. 3.

‡ Kayser, 'Astrophysical Journal,' vol. 14, p. 313.

§ Julius, "Anomalous Refraction Phenomena investigated with the Spectroheliograph," 'Contributions from the Mount Wilson Solar Observatory,' No. 29 ; 'Astrophysical Journal,' vol. 28, December, 1908.

paths, opposite in curvature and therefore widely separated in the solar atmosphere. It is improbable that equal amounts of light would reach the slit in both cases, and thus the resulting images might be very different.

Consider, for example, the effect of a density gradient in a mass of vapour near a sun-spot. The anomalous refraction thus caused might deviate the direct light of the photosphere from the collimator slit. But if the camera slit were set, let us assume, on the red side of the line, the curvature of the path would be such as to bring the feeble light of the spot upon the slit; while if it were set on the violet side of the line, the bright light of the photosphere would enter. Hence the resulting images should differ greatly.

We have thus been led to try the effect of photographing the flocculi with light from the red and violet sides of $H\alpha$. In order to eliminate differences in the images due to irregular refraction in the earth's atmosphere at the times of exposure, the device already described for making simultaneous photographs with both parts of the line was employed in the 30-foot spectroheliograph (p. 181). The dispersion of a 60° prism, filled with ethyl cinnamate and twice traversed by the light, was sufficient to allow the slits to be set with precision on opposite sides of the $H\alpha$ line at equal distances from the centre. A control microscope, with cross-hair set on another line in the spectrum, permitted the adjustments to be checked during the exposure.

Many pairs of photographs made in this way have been compared with the stereocomparator. In general, the two images are almost identical in their principal features, though small differences of detail are often visible. In the case of eruptive phenomena the images are very unlike, as the distortion of the $H\alpha$ line would lead one to expect. Some remarkable examples of this kind, which can probably be explained satisfactorily on the basis of the Doppler effect, will be illustrated in subsequent papers.

The results obtained in this preliminary investigation of anomalous refraction phenomena in the sun can hardly be considered favourable to Julius' theory. The small differences frequently observed when comparing images given by opposite sides of $H\alpha$ are, perhaps, due to anomalous refraction, but the principal phenomena of the dark hydrogen flocculi may be explained more satisfactorily as absorption effects. Our work on anomalous refraction has just begun, however, and further investigations may render necessary some modification of this opinion.

FIG. 1

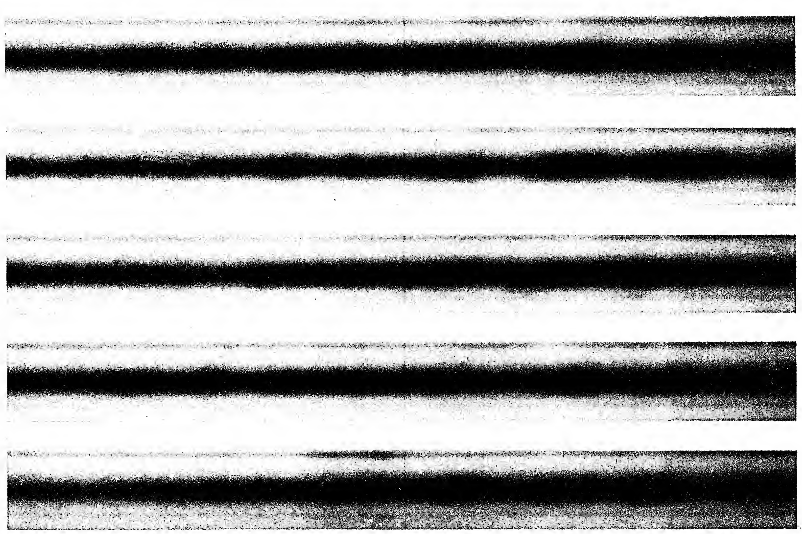

FIG. 2

DESCRIPTION OF PLATE.

FIG. 1.—Bright and dark hydrogen flocculi near active sun-spot group, 1908, September 2, 5 h. 36 m. P.M. Pacific standard time.

Photographed with Snow telescope and 5-foot spectroheliograph, camera slit 0·06 mm. (1·4 Ångströms) wide set on the hydrogen line Hα.

Scale of reproduction: Sun's diameter = 400 mm.

FIG. 2.—Five images of the Hγ line, showing it to be strengthened and widened in the dark hydrogen flocculi.

On the Distribution of the Röntgen Rays from a Focus Bulb.

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(Communicated by Prof. Sir J. J. Thomson, F.R.S. Received November 3,—Read December 9, 1909.)

This paper contains an account of some preliminary experiments on the distribution of the Röntgen rays under conditions similar to those which obtain in a modern focus bulb. The experiments which were carried out at the beginning of the year are being continued, but it has been thought well to put the results on record for reasons which will appear.

The distribution of X-rays as they proceed from their source excited interest even in the earliest forms of Röntgen bulbs, where the rays were generated by the impact of cathode rays against the glass walls of the tube. Sir J. J. Thomson* noticed that in such a case more X-rays come out from any point normally than obliquely; he explained this as due to the greater absorption and enfeeblement of the oblique rays which have a longer path in the glass.

Prof. Thomson also showed, by using a hemispherical photographic film, that when cathode rays strike at 45° against a flat plate, the Röntgen rays produced come off approximately uniformly in all directions until we approach quite close to the plane of the plate.

Prof. S. P. Thompson† similarly observed in 1897 that the intensity remains nearly uniform up to a grazing angle, where it abruptly ends. Campbell Swinton‡ records an observation to the effect that, with an anti-

* 'Conduction of Electricity through Gases,' 2nd edition, p. 646.

† Thompson, 'Phil. Trans.,' A, vol. 190, p. 471, 1897.

‡ Swinton, 'Roy. Soc. Proc.,' vol. 63, p. 432, 1898.

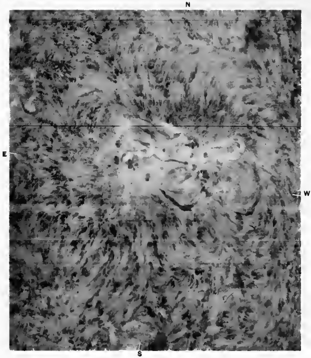

FIG. 1

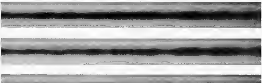

FIG. 2

DESCRIPTION OF PLATE.

FIG. 1.—Bright and dark hydrogen flocculi near active sun-spot group, 1908, September 2, 5 h. 36 m. P.M. Pacific standard time.

Photographed with Snow telescope and 5-foot spectroheliograph, camera slit 0·06 mm. (1·4 Ångstroms) wide set on the hydrogen line Hα.

Scale of reproduction : Sun's diameter = 400 mm.

FIG. 2.—Five images of the Hγ line, showing it to be strengthened and widened in the dark hydrogen flocculi.